Using Exposure Management to Control India’s Health Burden From Air Pollution

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## The world’s most polluted cities are in India

PM 2.5 (micrograms per cubic meter) in the most polluted cities worldwide in 2014

<table>
<thead>
<tr>
<th>City</th>
<th>PM 2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delhi</td>
<td>153</td>
</tr>
<tr>
<td>Patna</td>
<td>149</td>
</tr>
<tr>
<td>Gwalior</td>
<td>144</td>
</tr>
<tr>
<td>Raipur</td>
<td>134</td>
</tr>
<tr>
<td>Karachi</td>
<td>117</td>
</tr>
<tr>
<td>Peshawar</td>
<td>111</td>
</tr>
<tr>
<td>Rawalpindi</td>
<td>107</td>
</tr>
<tr>
<td>Khormabad</td>
<td>102</td>
</tr>
<tr>
<td>Ahmedabad</td>
<td>100</td>
</tr>
<tr>
<td>Lucknow</td>
<td>96</td>
</tr>
<tr>
<td>Firozabad</td>
<td>96</td>
</tr>
<tr>
<td>Doha</td>
<td>93</td>
</tr>
<tr>
<td>Kanpur</td>
<td>93</td>
</tr>
<tr>
<td>Amritsar</td>
<td>92</td>
</tr>
<tr>
<td>Ludhiana</td>
<td>91</td>
</tr>
</tbody>
</table>

Source: WHO
1990: 85%: 700 million people using solid fuels

Today: 60%: 700 million people

~1980 700 million people in entire country

700 million people caught in the “Chulha Trap”

One-quarter of world total
First person in human history to have her exposure measured doing the oldest task in human history

~500 ug/m³
For 24 hours

Kheda District
Gujarat, 1981
India, Both sexes, All ages, 2013

High blood pressure: ~9.3 lakh/y
Household air pollution: ~6 lakh/y
High fasting plasma glucose: ~6 lakh/y
Smoking: ~6 lakh/y
High sodium: ~5 lakh/y
Low fruit: ~3 lakh/y
High total cholesterol: ~3 lakh/y
Ambient particulate matter: ~3 lakh/y
Alcohol use: ~2.5 lakh/y
High body-mass index: ~2.5 lakh/y
Unsafe water: ~2.0 lakh/y
Low physical activity: ~1.5 lakh/y
Integrated Exposure-Response (IER)

- Combines health effects studies of outdoor air pollution, secondhand tobacco smoke, household air pollution, and active smoking
- Now have IER curves for 5 major diseases caused by combustion particle air pollution
- Bolsters evidence base overall
- And allows for consistent comparisons
Integrated Exposure-Response: Ambient Air, SHS, and Smoking and Heart Disease

Ischemic Heart Disease

HAP Zone

Ambient Air Pollution

Secondhand Tobacco Smoke

Smokers

CRA, 2014
Ischemic Heart Disease

ALRI

COPD

Lung Cancer

Stroke

ug/m³ annual average PM$_{2.5}$
India IHD female DALYs
9,090,000 DALYs

Tobacco smoking (including SHS) 6.0%
Household air pollution 21%
Ambient PM pollution 16%
Other 42%

Smith/Bruce, et al., 2014
Compared to What?

- Ambient air pollution – ~98% cleanest city in the world ~7 ug/m3 PM2.5
- Household air pollution – cooking with gas ~ 7 ug/m3 PM2.5
%PM$_{2.5}$ from “Residential” Emissions: NASA
Percent of primary ambient PM$_{2.5}$ from household cooking fuels – population weighted

~25% in India

Chafe, et al., 2014
<table>
<thead>
<tr>
<th>Country</th>
<th>Deaths ($\times 10^3$)</th>
<th>Residential energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>1,357</td>
<td>32 (76)</td>
</tr>
<tr>
<td>India</td>
<td>645</td>
<td>50 (77)</td>
</tr>
<tr>
<td>Pakistan</td>
<td>111</td>
<td>31 (67)</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>92</td>
<td>55 (78)</td>
</tr>
<tr>
<td>Nigeria</td>
<td>89</td>
<td>14 (31)</td>
</tr>
<tr>
<td>Russia</td>
<td>67</td>
<td>7 (18)</td>
</tr>
<tr>
<td>USA</td>
<td>55</td>
<td>6 (12)</td>
</tr>
<tr>
<td>Indonesia</td>
<td>52</td>
<td>60 (64)</td>
</tr>
<tr>
<td>Ukraine</td>
<td>51</td>
<td>6 (13)</td>
</tr>
<tr>
<td>Vietnam</td>
<td>44</td>
<td>51 (74)</td>
</tr>
<tr>
<td>Egypt</td>
<td>35</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Germany</td>
<td>34</td>
<td>8 (17)</td>
</tr>
<tr>
<td>Turkey</td>
<td>32</td>
<td>9 (20)</td>
</tr>
<tr>
<td>Iran</td>
<td>26</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Japan</td>
<td>25</td>
<td>12 (29)</td>
</tr>
<tr>
<td>World</td>
<td>3,297</td>
<td>31 (59)</td>
</tr>
</tbody>
</table>

Percent of outdoor air pollution from households in India.
Household energy consumption (HEC) emissions were calculated in four classes - cooking (CK), lighting (LG), space heating (SH), and water heating (WH). Bottom-up emissions for the four classes are available at 0.25 degree spatial resolution, and further aggregated to district and state level. A sub-classification is available by fuel - biomass, coal, kerosene, liquefied petroleum gas (LPG), and others.

%Households Primary Cooking Fuel
gas+elec others
3.2% 96.8%

District Emissions

- PM$_{2.5}$
- CO$_2$
- BC

Estimated district annual HEC emissions
- Particulates (2.5μm): 11,780 tons
- Sulfur dioxide: 840 tons
- Nitrogen oxides: 1,165 tons
- Carbon monoxide: 145,400 tons
- Hydrocarbons: 20,900 tons
- Black carbon (BC): 2,550 tons
- Organic carbon: 4,560 tons
- Carbon dioxide (CO$_2$): 0.22 mil tons

Estimated PM$_{2.5}$ emissions @ 0.25 degree resolution

Modeled share of HEC emissions to ambient PM$_{2.5}$

- WH: 12%
- SH: 19%
- CK: 63%
- LG: 6%

% contribution of HEC emissions to modeled ambient PM$_{2.5}$ concentrations

- National: 29.6%
- District: 38.2%

The health impacts of outdoor air pollution is ischemic heart diseases (which can lead to heart attacks), cerebrovascular disease (which can lead to strokes), chronic obstructive pulmonary diseases, lower respiratory infections, and cancers (in trachea, lungs, and bronchitis) were estimated using the age-dependent relative risk functions detailed in the Global Burden of Disease study (2013) and dispersion modeling results from this study. The final calculations were conducted at the district level using the population distribution by age presented in.

Estimated premature mortality of outdoor air pollution per year - apportioned to HEC emissions

- National: 59,000 - 72,000
- District: 136 - 173
Percent of outdoor air pollution mortality from household fuels

- Varies by model and databases used
- 25-50% in India
- 14-30% globally
- Household sources are as important as any other sector, and sometimes more than vehicles, industries, power plants, etc.
Recent trends give us an idea where we are going if nothing is done.
The Environmental Risk Transition

• How do environmental and other health risks trend during economic development?
• Not uniform in every country at every period,
• But broadly the case both historically and in cross section.
• India in a unique place historically
The Environmental Risk Transition
The Environmental Risk Transition

Risk

Development

Traditional Risk

Modern Risks
India

- Still with ~two-thirds of households using solid cookfuels – only part way down the traditional risk curve
- Most polluted cities in the world – peak of the modern risk curve
- Highest burden of disease from air pollution in the world – greatest risk overlap
- Highest total air pollution burden/capita of all middle-income countries – 2x China
Ministry of Health and Family Welfaren 2015, “Report of the Steering Committee on Air Pollution and Health Related Issues”

- First Ministry of Health in world to treat AP as one of its major priorities and consider along with other risk factors in its mission
- First government agency in the world not to address AP by location, but by total exposure – a true health focus
- Thus, not indoor/household, not outdoor, but by what will give the most health benefit
Eventually, we wish to control all sources of air pollution, all the time, everywhere.

But we cannot afford to do so immediately.

What metric gives the optimal pathway such that the most health protection is occurring at each stage of investment?

Only metrics of exposure are a practical way to do so.
Exposure is a much better metric for understanding and controlling health risk.

Classic air pollution control focuses on concentrations in fixed locations.
Source – Exposure Relationships

How different? Does it matter?

Vehicles

Power plants

Stoves
MoHFW AP Task Force

• Total exposure approach requires utilizing estimates degree of exposure due to each source category.
• Emissions weighted essentially by proximity to population
• Goal is to change source apportionment to exposure apportionment
• Control not in a particular place, but where the people are
Exposure apportionment methods

- Intake fractions by category
- Population weighted personal exposure assessment with source apportionment
- Micro-environmental source apportionment
- Modeling
- Many new tools available including sensor networks, satellite observations, GIS mapping, small/cheap monitors, etc
One Approach is Intake Fraction

IF is the fraction of material emitted that is actually breathed in by someone

Ranges from 1,000 to 10 ppm (grams inhaled per tonne emitted)
IF = one million ppm – all is breathed in.

Worse thing you can do.
<table>
<thead>
<tr>
<th>Source</th>
<th>Average</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste burn</td>
<td>109.9</td>
<td>14.6</td>
</tr>
<tr>
<td>Veh. exhaust</td>
<td>89.4</td>
<td>11.6</td>
</tr>
<tr>
<td>Gen. sets</td>
<td>89.1</td>
<td>14.6</td>
</tr>
<tr>
<td>Construction</td>
<td>85.9</td>
<td>10.4</td>
</tr>
<tr>
<td>Households</td>
<td>76.3</td>
<td>12.0</td>
</tr>
<tr>
<td>Dust</td>
<td>63.2</td>
<td>9.6</td>
</tr>
<tr>
<td>Industries</td>
<td>36.9</td>
<td>11.0</td>
</tr>
<tr>
<td>Brick. kilns</td>
<td>11.6</td>
<td>17.8</td>
</tr>
<tr>
<td>Power plants</td>
<td>8.1</td>
<td>8.4</td>
</tr>
</tbody>
</table>
Emissions – PM$_{2.5}$
MoHFW Report estimates by Guttikunda

Exposures – PM$_{2.5}$

Chennai-2012
Intake Fraction, cont.

- Nearfield intake fractions not yet as well developed but important for local sources
  - Vehicles
  - Neighborhood waste burning
  - Gen sets
  - Households

- Preliminary estimates of household nearfield intake fractions are about 10x those from ambient (downwind exposures) in Chennai (750 vrs 75 ppm)
Source – Exposure Relationships

Vehicles

Power plants

Stoves

How different? Does it matter?

Yes, a factor of 100 different!
Classic air pollution control focuses on concentrations in fixed locations. Integrated exposure allows for more nuanced and efficient air pollution control that weights sources by their impact on exposure and health rather than environmental quality.
Deaths from air pollution in 2013

Air pollution was responsible for 5.5 million deaths in 2013

Source:
India’s situation today not like Europe and North America in the past

- Traditional and modern sources both strong at once
- Population density much higher – what was OK once is not so any longer
- Traditional and modern intermingled – each affect each other
- Understanding of health effects changed
- Scientific methods have evolved
India and Air Pollution, summary

• Not only the highest burden of disease from air pollution in the world, but also among the highest burdens per capita
• Will get worse if current trends continue
• Both ambient and household pollution important
• And they are connected
• New approaches to control needed
• And available
Many thanks

For publications and presentations: Just “Google”

Kirk R. Smith